Cook Shire Council

Webber Esplanade
Rock Revetment Review

April 2016

Executive Summary

Cook Shire Council has engaged GHD in an advisory role, supporting Council in its response to the concerns raised with regards to the Webber Esplanade waterfront project by the Department of Environment and Heritage Protection (EHP). EHP is currently investigating a complaint raised regarding the construction of the revetment wall at Webber Esplanade, as outlined in their letter to Cook Shire Council, dated 2 December 2015.

GHD completed a desktop review and provided an initial response to EHP's concerns in a memo report dated 5 February 2016. Our memo report recommended a number of actions, becoming the basis for further site investigation and reporting. On the 17 and 18 February 2016, GHD worked with Council on undertaking a series of 'peel backs' in order to assess the revetment composition and build.

Four (4) 'peel backs' confirmed the following defects with the existing revetment structure:

- Undersized armour and underlayer material, which is too widely graded and outside of typical specification for static revetment structures.
- Poor interlocking and unacceptable porosity of armour rock leading to unacceptable safety and performance risk.

Rock testing results show that the rock utilised within the structure is highly variable with assessed durability rating ranging from 'poor to excellent' in accordance with CIRIA guidance. The high variability is likely to lead to high maintenance and a reduction in revetment performance against extreme events over time.

Based on the findings of this report and the defects identified herein, it is confirmed that the existing revetment structure does not comply with the minimum design criteria in EHP's operational policy, building and engineering standards for tidal works.

As a result of this report, it was considered appropriate that a failure modes analysis and qualitative risk assessment be undertaken in order to assist Council and EHP make appropriate decisions with respect to the revetment structure. It is emphasised that the level of risk acceptable to EHP is currently unknown and has not been defined by EHP to date. Due to the lack of documented and available information over the complete cycle of project evolution, the proposed risk assessment is appropriately qualified as providing no future risk profile guarantees. There is an underlying onus by Council and EHP to accept the actual and unknown level of risk and any remediation strategy proposed may not lead to a residual risk profile which either achieves EHP's tidal works criteria and/or a defined Council/EHP risk profile.

Prior to any works being undertaken or remediation solution being fully developed, whether it be revetment remediation and/or further topside structural works, it is recommended that Cook Shire Council in consultation with the Department of Natural Resources and Mines (DRNM) and the Maritime Safety Queensland (MSQ) Harbourmaster, determine an acceptable revetment footprint in order to fully inform any potential remediation design.

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1. Introduction

EHP is currently investigating a complaint raised regarding the construction of the revetment wall within the Webber Esplanade waterfront development. Prior to this report, GHD completed a desktop review and provided an initial response to EHP's concerns in a memo report dated 5 February 2016, attached in Appendix A for completeness. To further address the alleged non-compliance conditions raised by EHP in their 2 December 2015 letter, the following activities have been undertaken:

- Site visual inspection of the revetment wall coupled with invasive 'peel back' sampling.
- Rock testing to a specification typically used for marine rock revetment works.

In addition, subsequent to the preparation of our memo report, a meeting occurred on the 17 February 2016 attended by EHP, Council and GHD representatives in the EHP Cairns office. For the purpose of GHD's site investigation, EHP confirmed its ultimate requirement that the revetment structure is required to comply with their operational policy, building and engineering standards for tidal works. Refer to EHP's minutes of meeting within Appendix B.

For context, GHD was the designer for the original design, which has been amended and reissued by others, and was constructed in the absence of any GHD presence. GHD therefore has no direct knowledge of the as-constructed works and foundation preparation, other than what is visible or revealed in recent investigations and any other provided information. The work undertaken and reported herein is for the relevant authorities to understand the inherent risks with the structure as-built, to the extent these can be reasonably and practicably ascertained after the event.

1.1 Purpose of this report

The purpose of this report is to document the site investigation activities completed on the 18 February 2016 and provide appropriate interpretation of results in order to assist in understanding the risks associated with the alleged non-compliance raised by EHP in their letter to Cook Shire, dated 02 December 2015.

1.2 Scope and limitations

This report has been prepared by GHD for Cook Shire Council and may only be used and relied on by Cook Shire Council for the purpose agreed between GHD and the Cook Shire Council as set out in section 1.1 of this report.

GHD otherwise disclaims responsibility to any person other than Cook Shire Council arising in connection with this report. GHD also excludes implied warranties and conditions, to the extent legally permissible.

The services undertaken by GHD in connection with preparing this report were limited to those specifically detailed in the report and are subject to the scope limitations set out in the report.

The opinions, conclusions and any recommendations in this report are based on conditions encountered and information reviewed at the date of preparation of the report. GHD has no responsibility or obligation to update this report to account for events or changes occurring subsequent to the date that the report was prepared. Site conditions may change after the date of this Report. GHD does not accept responsibility arising from, or in connection with, any change to the site conditions. GHD is also not responsible for updating this report if the site conditions change.

GHD has prepared this report on the basis of information provided by Cook Shire Council and others who provided information to GHD (including Government authorities), which GHD has not independently verified or checked beyond the agreed scope of work. GHD does not accept liability in connection with

such unverified information, including errors and omissions in the report which were caused by errors or omissions in that information.

1.3 Assumptions and definitions

The conclusions and findings within this report are based on the consistency of results between the limited revetment 'peel backs' and revetment rock test sampling. [redacted] supervised both the 'peel backs' and selection of rocks required for sample testing. Anthony has assessed the in situ rock revetment structure and its expected performance with respect to EHP's operational policy, building and engineering standards for tidal works against the following amended and approved drawings:

- 'Cook Shire Council' – Webber Esplanade – Cooktown – Revetment Wall – As Built Design General Arrangement Plan', Reference No CSC-C001, Version A1, dated 20/05/2014.
- 'Cook Shire Council' – Webber Esplanade – Cooktown – Revetment Wall – As Built Design Sections Sheet 1 of 2', Reference No CSC-C002, Version A1, dated 20/05/2014.
- 'Cook Shire Council' – Webber Esplanade – Cooktown – Revetment Wall – As Built Design Sections Sheet 2 of 2', Reference No CSC-C003, Version A1, dated 20/05/2014.

Structural assessment of either adjacent and/or interfacing structures to the rock revetment has not been undertaken within this investigation.

The following definitions are provided and stated for reader clarity;

- Armour rock – Outer layer/s of rock directly exposed to wave attack.
- Underlayer rock – Inner layer of rock on which armour is founded. Sometimes an underlayer is called a filter, hence the requirement for clarification.
- Filter material – typically consists of a geotextile material suitable for marine revetment works.

2. Invasive ‘peel back’ sampling

2.1 Locations

A total of four (4) ‘peel backs’ were undertaken along the revetment extent, numbered 1, 2, 3, and 5 as shown below in Figure 1. ‘Peel back’ number 4 was not completed due to the constraints of existing built infrastructure. On the basis of generally consistent results observed at the 4 locations where “peel backs” were undertaken (1, 2, 3 and 5), it was concluded on site that ‘peel back’ number 4 would provide little value for the high costs to complete.

Figure 1 ‘Peel back’ locations

A summary of findings and the extent to which the construction of the wall complied with both the amended approved drawings and EHP’s operational policy, building and engineering standards for tidal works are provided below.

2.2 Test pit 1

Test pit 1 ‘peel back’ occurred at the eastern end of the revetment, as shown in Figure 1. Observations are noted below in Table 1.

Table 1 Test pit 1 summary

	'Peel back' item	Compliant with amended and approved CSC drawings	Compliance with EHP's operational policy, building and engineering standards for tidal works (column 2, G)
1.	**Toe rock** has been placed on the seabed, generally 2 to 3 rocks in length, and sized generally in accordance with the amended approved drawing CSC-C002 rev 0. See photo 15 below, in particular. The toe rock generally exceeds the specified D_n50 900 mm, typically ranging from 1 to 2 metres in diameter.	Yes, based on an assumed rock density of 2.6 t/m^3	Yes, toe rock provides allowance for scour.
2.	**Armour rock** on the slope has a wide grading, generally ranging from 30 mm (D_{min}) to 1500 mm (D_{max}). See photos 4 to 7, 11 to 14 and 21 to 28 below, in particular.	No	No, under sized armour rock non-compliant with design storm event criteria
3.	**Armour porosity** too high with poor interlocking evident. Some armour rock is unstable under foot. It appears likely that rock was end dumped from truck tipper as opposed to being selectively placed by excavator in 2 layers. See photos 2 and 17, below in particular.	*Strictly not specified*	No, under sized armour rock non-compliant with design storm event criteria
4.	**Underlayer rock** has too wide a grading, with a high fraction of small rock. It appears likely that rock was end dumped from truck tipper as opposed to being selectively placed by excavator in 2 layers. See photos 21 to 28 below, in particular.	No	No, under sized underlayer rock non-compliant with design storm event criteria
5.	**Core material** consists of sand and gravel material. Based on the core material removed, it is conservatively estimated that the fine sand material fraction exceeds 50% passing. See photos 21 to 28 below, in particular.	No	No, fine material non-compliant with design storm event criteria

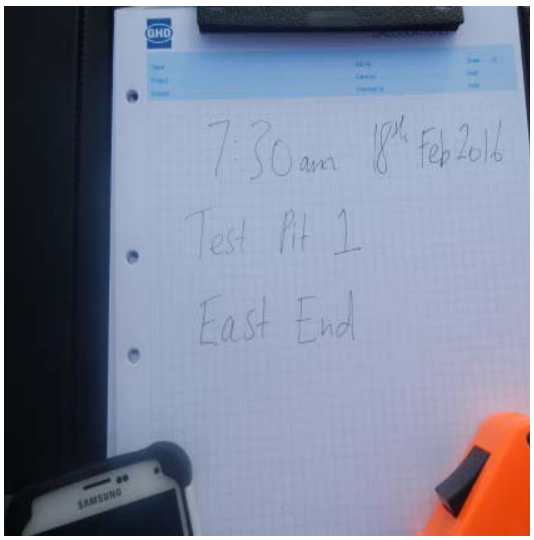


Photo 1

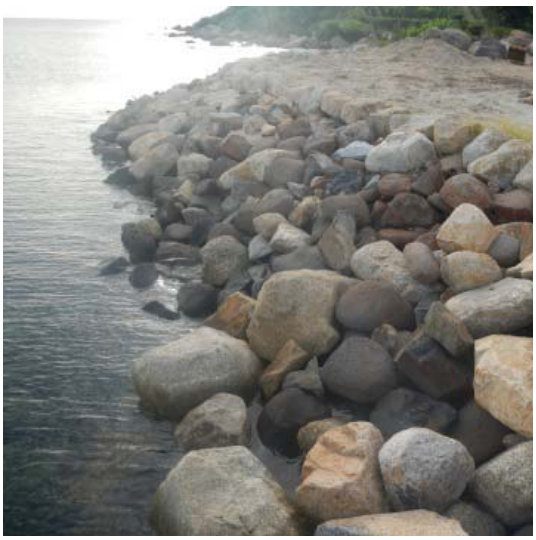


Photo 2

Photo 3

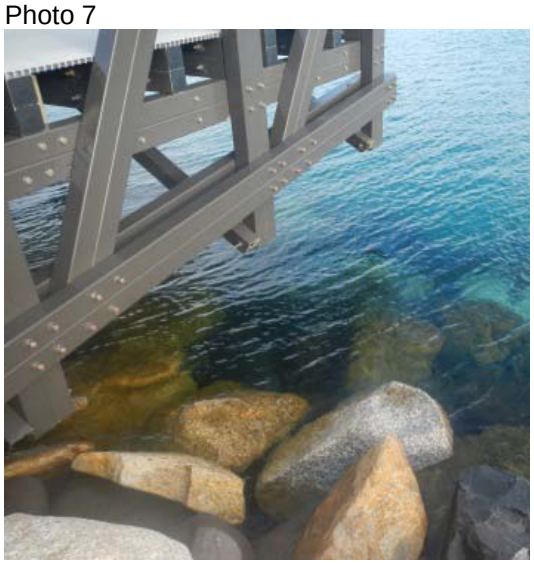
Photo 4

Photo 5

Photo 6

Photo 7

Photo 8



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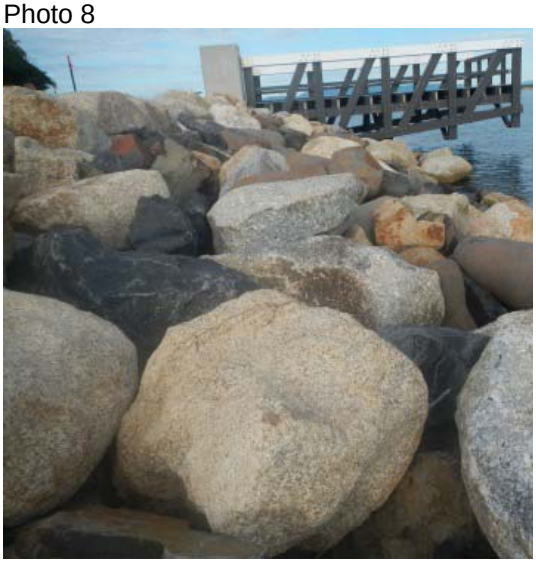

Photo 10

Photo 11

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Photo 13

Photo 14

Photo 15

Photo 16

Photo 17

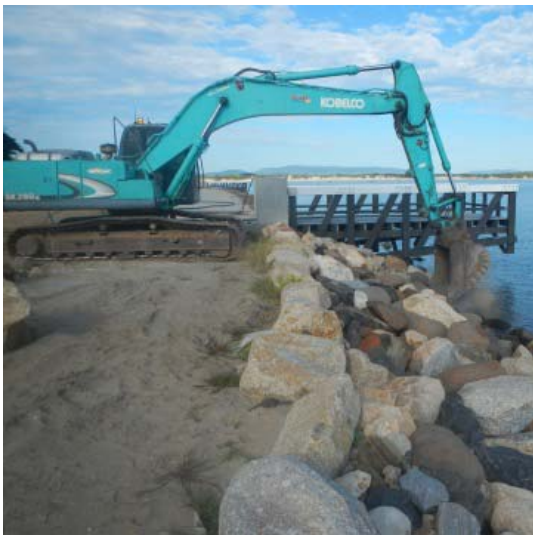


Photo 18

Photo 19

Photo 20

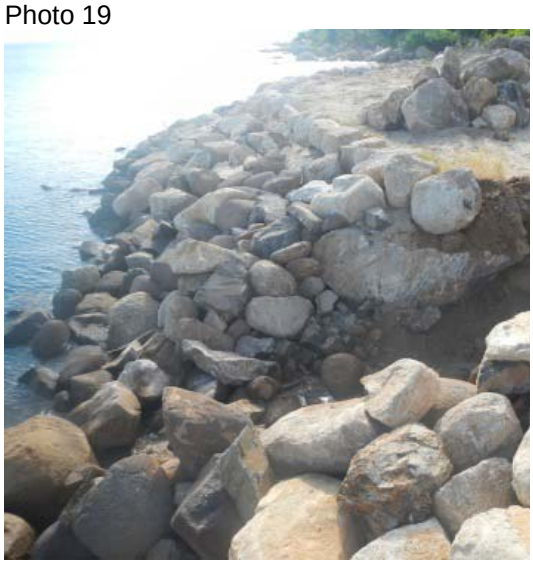


Photo 21

Photo 22

Photo 23

Photo 24

Photo 25

Photo 26

Photo 27

Photo 28

3. Test pit 2

Test pit 2 'peel back' occurred at the location shown above in Figure 1. Observations are noted below in Table 2.

Table 2 Test pit 2 summary

	'Peel back' item	Compliant with amended and approved CSC drawings	Compliance with EHP's operational policy, building and engineering standards for tidal works (column 2, G)
1.	**Toe rock** has been placed, generally 2 to 3 rocks in length, and sized generally in accordance with the amended approved drawing CSC-C002 rev 0. See photos 36 and 37 below. The toe rock generally exceeds the specified D_n50 900 mm, typically ranging from 1 to 2 metres in diameter.	Yes, based on an assumed rock density of 2.6 t/m^3	Yes, toe rock provides allowance for scour.
2.	**Armour rock** on the slope has a wide grading, generally ranging from 30 mm (D_{min}) to 2000 mm (D_{max}). Two distinct layers of rock armour not placed. See photos 47 to 50 below, in particular.	No	No, under sized armour rock non-compliant with design storm event criteria
3.	**Armour porosity** too high with poor interlocking evident. It appears likely that rock was end dumped from truck tipper as opposed to being selectively placed by excavator in 2 layers. See photos below.	*Strictly not specified*	No, under sized armour rock non-compliant with design storm event criteria
4.	**Underlayer rock** has too wide a grading, with a high fraction of small rock. It is likely that rock was end dumped from truck tipper as opposed to being selectively placed by excavator in 2 layers. See photos 47 to 50 below, in particular.	No	No, under sized underlayer rock non-compliant with design storm event criteria
5.	**Core material** consists of sand and gravel material. Based on the core material removed, it is conservatively estimated that the fine sand material fraction exceeds 50% passing. See photos 49 to 53 and 57 below, in particular.	No	No, fine material non-compliant with design storm event criteria

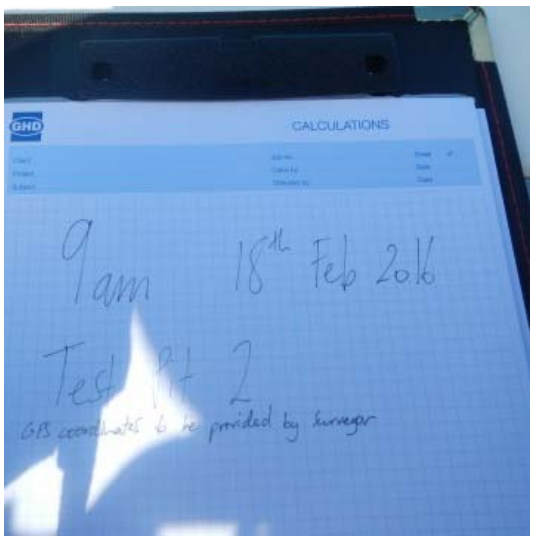
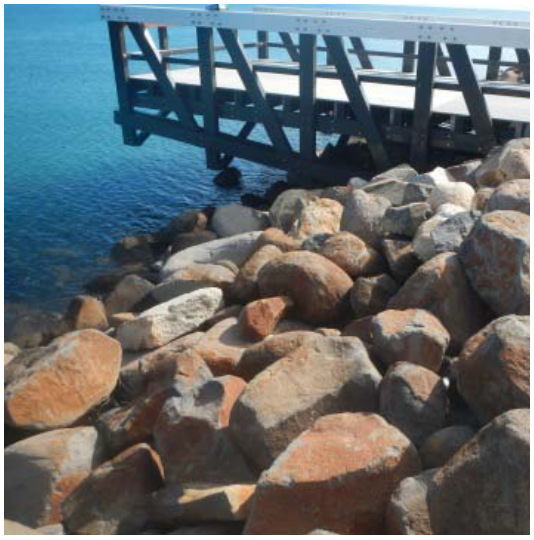


Photo 29

Photo 30



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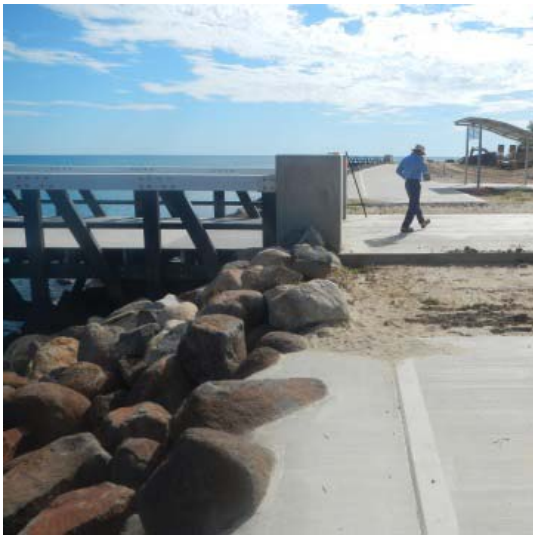


Photo 32

Photo 33

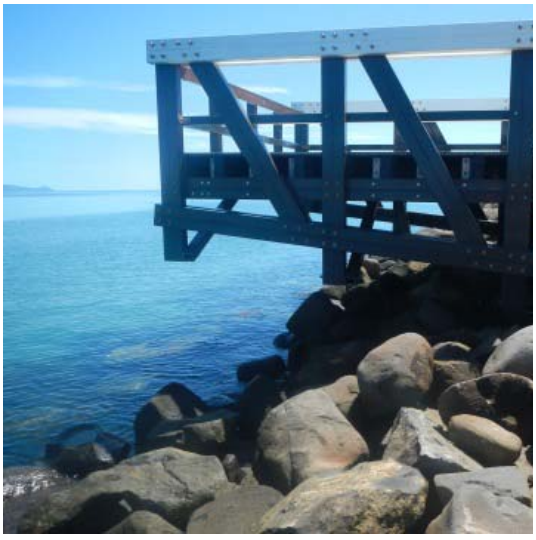


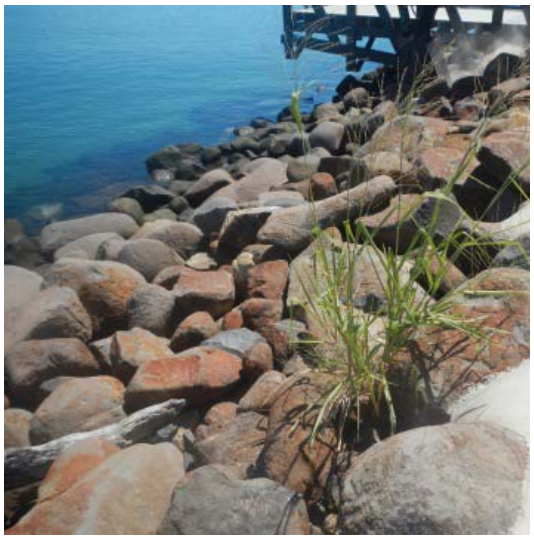
Photo 34 -

Photo 35

Photo 36

Photo 37

Photo 38



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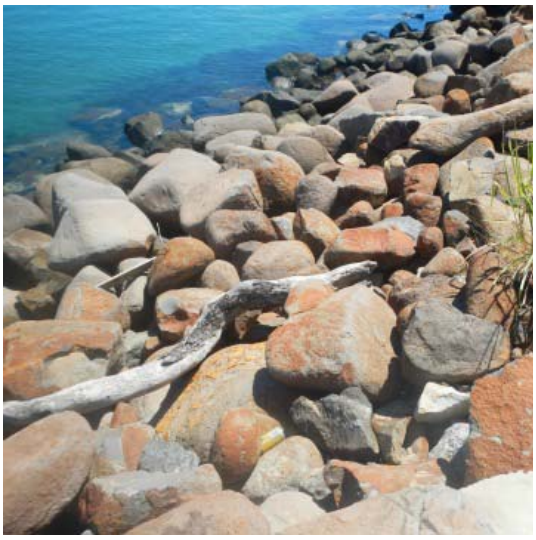

Photo 40

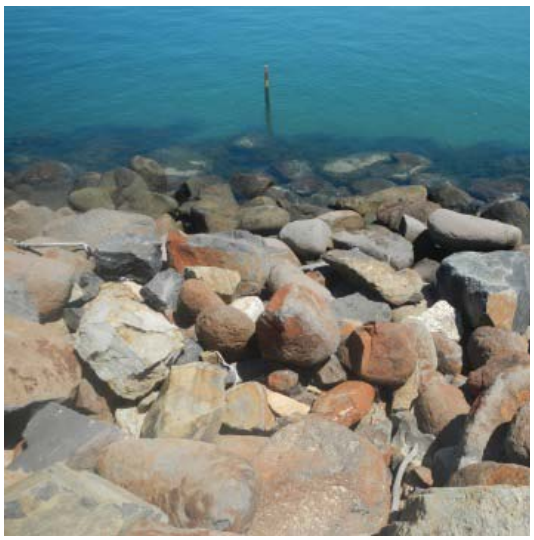

Photo 41

Photo 42

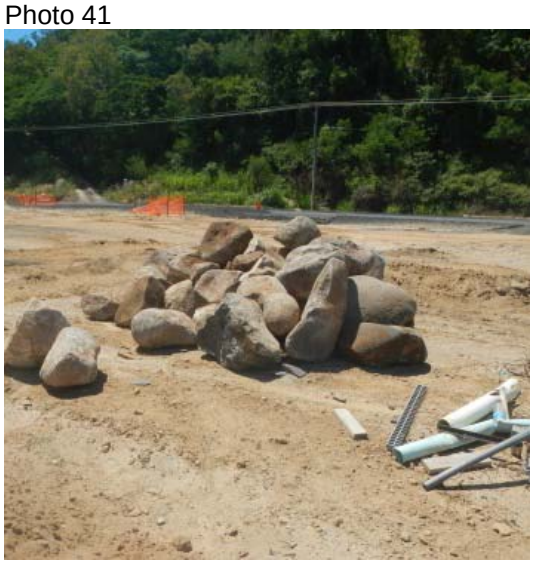

Photo 43

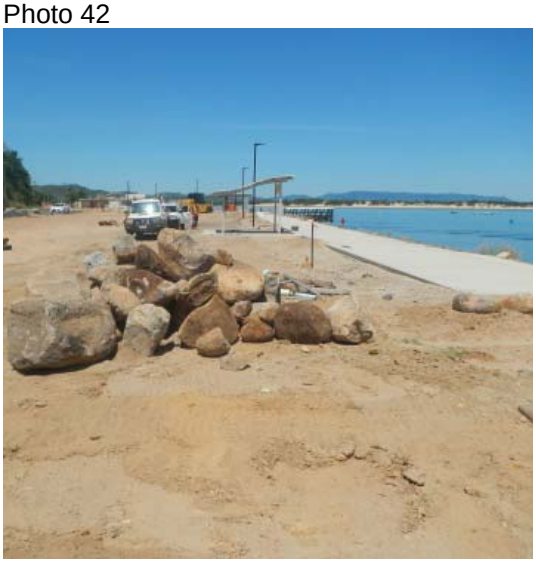

Photo 44

Photo 45

Photo 46

Photo 47

Photo 48

Photo 49

Photo 50

Photo 51

Photo 52

Photo 53

Photo 54

Photo 55

Photo 56

Photo 57

4. Test pit 3

Test pit 3 'peel back' occurred at the location shown above in Figure 1. Observations are noted below in Table 3.

Table 3 Test pit 3 summary

'Peel back' item		Compliant with amended and approved CSC drawings	Compliance with EHP's operational policy, building and engineering standards for tidal works (column 2, G)
1.	**Toe rock** is close to the navigation channel and generally consists of 1 rock only.	No	No, reduced toe rock increases the risk of structure slumping due to scour.
2.	**Armour rock** on the slope has a wide grading, generally ranging from 30 mm (D_{min}) to 1500 mm (D_{max}). See photo 60 in particular.	No	No, under sized armour rock non-compliant with design storm event criteria
3.	**Armour porosity** too high with poor interlocking evident. Some armour rock is unstable under foot. It appears likely that rock was end dumped from truck tipper as opposed to being selectively placed by excavator in 2 layers.	*Strictly not specified*	No, under sized armour rock non-compliant with design storm event criteria
4.	**Underlayer rock** has too wide a grading, with a high small rock fraction. It is likely that rock was end dumped from truck tipper as opposed to being selectively placed by excavator in 2 layers.	No	No, under sized underlayer rock non-compliant with design storm event criteria
5.	**Core material** consists of sand and gravel material. Based on the core material removed, it is conservatively estimated that the fine sand material fraction exceeds 50% passing. See photo 66 in particular.	No	No, fine material non-compliant with design storm event criteria

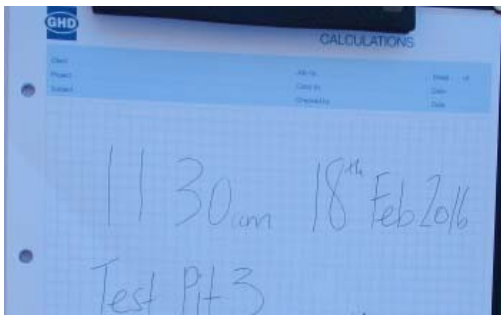

Photo 58


Photo 59


Photo 60


Photo 61

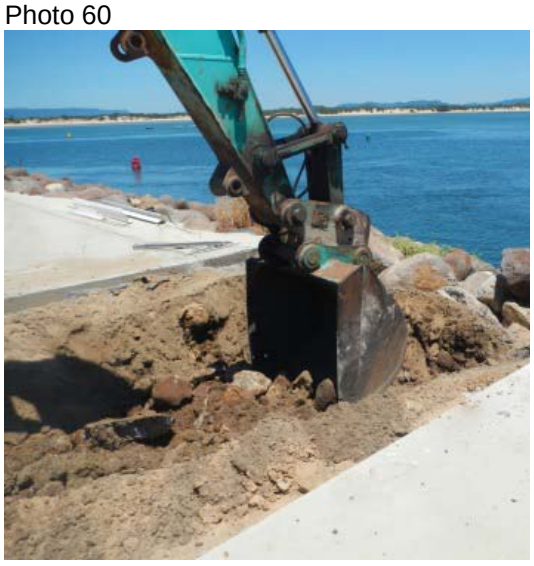
Photo 62


Photo 63

Photo 64

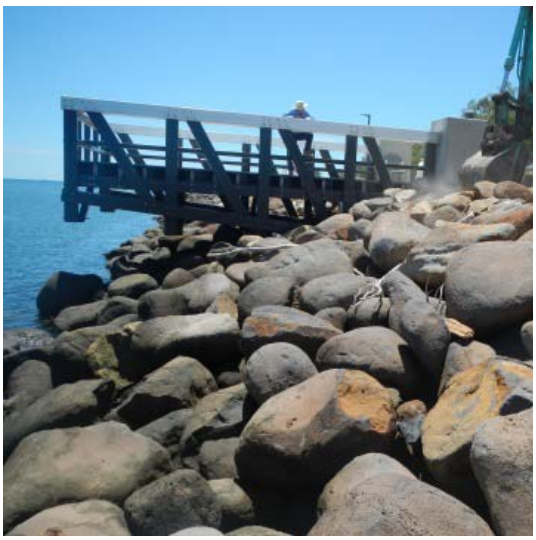

Photo 65

Photo 66

Photo 67

5. Test pit 5

Test pit 5 'peel back' occurred at the western end of the revetment structure as shown above in Figure 1. Observations are noted below in Table 4.

Table 4 Test pit 4 summary

'Peel back' item		Compliant with amended and approved CSC drawings	Compliance with EHP's operational policy, building and engineering standards for tidal works (column 2, G)
1.	It is not clear whether **Toe rock** has been placed within the revetment structure. Visual inspection was not possible, due to water depth and proximity of the adjacent channel.	Unknown	Unknown
2.	**Armour rock** on the slope has a wide grading, generally ranging from 30 mm (D_{min}) to 2000 mm (D_{max}). See photo 71 below.	No	No, under sized armour rock non-compliant with design storm event criteria
3.	**Armour porosity** too high with poor interlocking evident. It appears likely that rock was end dumped from truck tipper as opposed to being selectively placed by excavator in 2 layers. See photos below.	*Strictly not specified*	No, under sized armour rock non-compliant with design storm event criteria
4.	**Underlayer rock** has too wide a grading, with a high small rock fraction. It appears likely that rock was end dumped from truck tipper as opposed to being selectively placed by excavator in 2 layers. See photos 70 and 71 below, in particular.	No	No, under sized underlayer rock non-compliant with design storm event criteria
5.	**Core material** consists of sand and gravel material. Based on the core material removed, it is conservatively estimated that the fine sand material fraction exceeds 50% passing. See photo 74 below, in particular.	No	No, fine material non-compliant with design storm event criteria

In addition to the above, it is evident that the channel is quite close to the revetment structure, and sections of revetment steeper than 1 vertical to 2 horizontal have been locally built around both interfaces with the marina.

Photo 68

Photo 69

Photo 70

Photo 71

Photo 72

Photo 73

Photo 74

6. Rock testing

Representative armour and underlayer rock was selected at each test pit for further testing at Cardno's Rockhampton laboratory. Photographic record of selected rock from each test pit and the results summary are provided below.

6.1 Test pit 1

Photographic record of rocks selected for testing from test pit 1 are provided below.

Photo 75

Photo 76

6.2 Test pit 2

Photographic record of rocks selected for testing from test pit 2 are provided below.

Photo 77

Photo 78

6.3 Test pit 3

Photographic record of rocks selected for testing from test pit 3 are provided below.

Photo 79

Photo 80

6.4 Test pit 5

Photographic record of the rocks selected for testing from test pit 5 are provided below.

Photo 81

Photo 82

In addition to the rock shown above, an additional ‘blue rock’ sample was taken. It was noted on site that a small fraction of amour consisted of angular ‘blue rock’, typically borne from quarry blast production, as shown typically in Figure 2. Note the large ‘blue’ armour rock at the crest adjacent along the bounds of the ‘peel back’ excavation.

Figure 2 Armour rock and test pit 1 interface

6.1 Results summary

The sampled rock was tested at Cardno's Rockhampton laboratory in accordance with the following suite of tests. A copy of the test results are saved in Appendix C.

Table 5 Rock testing summary

Characteristic	Standard	Typical criterion	Test results				
			T1	T2	T3	Blue Rock	T5
Saturated surface-dry relative density	Sampled, tested and reported in accordance with AS 4133.2.1.2 – rock density tests	For armour and underlayer 2,600 kg/m^3 minimum	2.549 t/m^3	2.554 t/m^3	2.344 t/m^3	2.786 t/m^3	2.548 t/m^3
Water absorption	Sampled, tested and reported in accordance with AS 4133.2.1.2 – rock porosity tests	For armour 2% maximum For underlayer 3% maximum	3.1%	7.5%	10.5%	1.3%	3.7%
Los Angeles abrasion test	AS 1141, Section 23	Loss shall not exceed 20%.	26%	31%	27%	11%	49%
Sodium sulphate soundness test	AS 1141, Section 24 for 5 cycles, the loss shall not exceed 2.5%	Loss shall not exceed 2.5%.	1.1%	0.3%	1.8%	0.1%	1.7%
Crushing resistance	Ultimate Compressive Strength (UCS) test in accordance with AS 4133.4.2.1	Armour and underlayer 100 MPa minimum	185.3, 159.3, 91.0 MPa	118.7, 80.6, 123.4 MPa	55.0, 51.1, 59.5 MPa	183.4, 92.7, 98.8 MPa	49.4, 46.4, 17.9 MPa
	The point load index (I_S50) (determined to AS 4133.4.1)	Armour and filter 3.5 MPa minimum Other quarry materials 2.3 MPa minimum	14.99	14.46	4.20	32.99	0.95

6.2 Mt Amos quarry

A visit to the local Mt Amos quarry was undertaken on the 18 February 2016 to inspect and assess the feasibility of sourcing additional rock for any remedial works. It is understood that further removal of overburden and blasting of the current rock face, as shown in photo 84, is feasible.

Photo 83

Photo 84

Photo 85

6.3 Results summary

Following on from the visit to Mt Amos quarry, rock testing results undertaken by Soil Engineering Services during November 2015, were made available to Cook Shire Council. A copy of the testing results is shown in Appendix D. A comparison of the rock testing results, provided by Soil Engineering Services, against a specification typically referred to for rock revetments is provided below in Table 6.

Table 6 Mt Amos quarry rock testing summary

Characteristic	Standard	Acceptance criterion		Test results	Acceptance
Saturated surface-dry relative density	Sampled, tested and reported in accordance with AS 4133.2.1.2 – rock density tests	For armour All other grades	2,600 kg/m^3 minimum 2,600 kg/m^3 minimum	2730 kg/m^3	Yes
Water absorption	Sampled, tested and reported in accordance with AS 4133.2.1.2 – rock porosity tests	For armour All other grades	2% maximum 3% maximum	0.2%	Yes
Los Angeles abrasion test	AS 1141, Section 23	For all grades	loss shall not exceed 20%.	11%,12%	Yes
Sodium sulphate soundness test	AS 1141, Section 24 for 5 cycles, the loss shall not exceed 2.5%	For all grades loss shall not exceed 2.5%.		0.4%, 0.6%, 0.7%	Yes
Crushing resistance	Ultimate Compressive Strength (UCS) test in accordance with AS 4133.4.2.1	Armour 100 MPa minimum Filter 100 MPa minimum		Not provided	n/a
	The point load index (I_S50) (determined to AS 4133.4.1)	Armour Other quarry materials	3.5 MPa minimum 2.3 MPa minimum	Not provided	n/a

As shown above, the majority of testing results are acceptable against our specification. It is noted however, that the crushing resistance UCS and point load index tests were not undertaken and in addition, it is unclear which part of the quarry face was sampled. In the event that remediation of the rock revetment takes place, additional rock testing, against the full suite of tests above, would be required for RPEQ review, prior to load out.

7. Results interpretation and discussion

7.1 'Peel backs'

The following discussion is provided for the purpose of:

- Summarising the 'peel back' findings.
- Highlighting the associated risks with the current build.
- Providing further comment to the alleged contravention to the amended approval conditions.

In summary, 'peel back' test pits numbered 1, 2, 3 and 5 generally provided a consistency of results, thereby providing a basis to draw appropriate conclusions and recommendations. In particular, the following defects were consistently evident within all 'peel backs', contrary to both the amended and approved CSC drawings (see Figure 3 for typical section) and EHP's operational policy, building and engineering standards for tidal works;

- The armour layer grading is too widely graded and outside typical static revetment grading specification. Undersized rock armour leads to unacceptable safety and performance risk.
- The armour layer porosity is too high, with poor interlocking evident, most likely due to poor placement techniques during construction. High porosity within the armour layer leads to unacceptable safety and performance risk.
- The underlayer is too widely graded and outside typical static revetment grading specification. It is most likely that the underlayer material was end dumped by truck tipper during construction, which is unacceptable practice for static revetment build within a marine environment.
- There is a high fines content in the core material leading to a high risk of fine material leaching out of the structure and reclamation over time. Leaching of fill material is likely to lead to settlement risk and further deterioration of the revetment and adjacent landside infrastructure. Further sampling and testing of both the core and rock armour would be required in order to confirm particle size distribution and rock grading curves to further assess and define the risk of high fines content release.

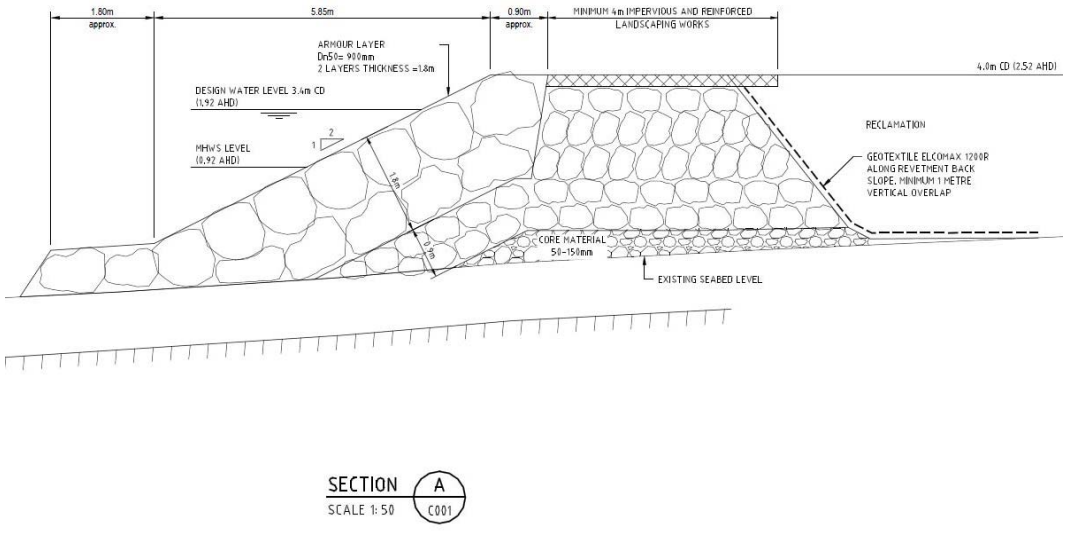

Figure 3 Typical amended approved revetment section (drawing no. CSC-C002)

In addition to the ‘peel backs’, a general walk over of the entire revetment was also undertaken. The following defects were evident and are considered unacceptable, in accordance with EHP’s operational policy, building and engineering standards for tidal works:

- Vegetation including growing grass and dead branches were found within the revetment structure.
- The revetment slope at the marina interface has been constructed to a slope steeper than 1 vertical to 2 horizontal. This has been confirmed by survey analysis in sketch sections 19 and 20 on GHD’s 41-29566 SK007, revision C. See Appendix E for updated survey analysis 41-29566 SK-001 to SK-008 revision C.

7.2 Rock testing

Rock testing has been undertaken on a sample of rock in order to assess durability risk. Review of the rock testing results, as summarised in Table 6 above, has been undertaken in accordance with CIRIA Rock Manual (2007).

Table 7 Guide to quality and durability of armourstone

	Quality and durability guide (not intended for specification purposes)					
	Criteria	Reference	Excellent	Good	Marginal	Poor
Laboratory Tests	Petrographic evaluation	Trained petrographer	**	**	**	**
	Mass density, ρ_{rock} (t/m^3)	EN 13383-2:2002	> 2.7	2.5–2.7	2.3–2.5	< 2.3
	Water absorption (%)	EN 13383-2:2002	< 0.5	0.5–2.0	2.0–6.0	> 6.0
	Microporosity/total porosity (%)	Lienhart (2003)	< 2	2–6	6–20	> 20
	Methylene blue adsorption (g/100g)	Verhoef (1992)	< 0.4	0.4–0.7	0.7–1.0	1.0
	Compressive strength (MPa)	EN 1926:1999	> 120	120–80	80–60	< 60
	Schmidt impact index (% rebound)	ISRM (1988)	> 60	50–60	40–50	< 40
	Sonic velocity (km/s)	EN 14579:2004	> 6	4.5–6	3–4.5	< 3
	Point load strength (MPa)	ISRM (1985)	> 8	4–8	1.5–4	< 1.5
	Fracture toughness (MPa.m$^{1/2}$)	ISRM (1988)	> 1.7	1.0–1.7	0.6–1.0	< 0.6
	Indirect tensile (Brazilian) strength (MPa)	ASTM D3967-95a (2004) ISRM (1978)	> 10	5–10	2–5	< 2
	Los Angeles (% loss)	EN 1097-2:1998	< 15	15–25	25–35	> 35
	Micro-Deval (% loss)	EN 1097-1:1996	< 10	10–20	20–30	> 30
	$MgSO_4$ soundness (% loss)	EN 1367	< 2	2–10	10–30	> 30
	Freeze-thaw (% loss)	EN 13383-2:2002	< 0.5	0.5–1	1.0–2	> 2
	Sonic velocity reduced by freeze-thaw (% change) ***	Section 3.8.6	< 5	5–15	15–30	> 30
	Wet-dry (% loss)	ASTM D5313-04	< 0.5	0.5–1	1.0–2	> 2

Sourced : CIRIA, C683 The Rock Manual, 2007

A durability assessment of rock testing results, against CIRIA criteria, is provided below in Table 8. In summary, the rock testing results vary considerably from ‘poor to excellent’ against the nominated characteristics. The ‘poor to marginal’ results introduce durability risk for the revetment structure particularly concerning maintenance and performance in extreme events.

Table 8 Rock testing summary

Characteristic	Durability assessment to CIRIA	Test results					
		T1	T2	T3	T5	Blue Rock	Mt Amos
Saturated surface-dry relative density	T1 to T5 – 'Marginal to Good' Blue Rock and Mt Amos Quarry – 'Excellent'	2.549 t/m^3	2.554 t/m^3	2.344 t/m^3	2.548 t/m^3	2.786 t/m^3	2.730 t/m^3
Water absorption	T1 to T5 – ''Marginal to Poor' Blue Rock – 'Good' Mt Amos Quarry – 'Excellent	3.1%	7.5%	10.5%	3.7	1.3%	0.2%
Los Angeles abrasion test	T1 to T5 – ''Marginal to Poor' Blue Rock and Mt Amos Quarry – 'Excellent'	26%	31%	27%	49%	11%	11%, 12%
Sodium sulphate soundness test	T1 to T5 – ''Excellent' Blue Rock and Mt Amos Quarry – 'Excellent'	1.1%	0.3%	1.8%	1.7%	0.1%	0.4%, 0.6%, 0.7%
Ultimate Compressive Strength (UCS)	T1 to T5 – ''Poor to Excellent' Blue Rock – 'Good to Excellent'	185.3, 159.3, 91.0 MPa	118.7, 80.6, 123.4 MPa	55.0, 51.1, 59.5 MPa	49.4, 46.4, 17.9 MPa	183.4, 92.7, 98.8 MPa	Not provided
The point load index (I_S50)	T1 to T5 – ''Poor to Excellent' Blue Rock – 'Excellent'	14.99	14.46	4.20	0.95	32.99	Not provided

7.2.1 Saturated surface-dry relative density

The saturated surface-dry relative density values of the T1 to T5 rock samples is assessed as 'marginal to good' quality in accordance with CIRIA. Density values range from 2.334 to 2.554 t/m^3. It is noted that GHD's original design adopted a value of 2.6 t/m^3. Typical implications of rock density non-conformance is to increase rock size to account for the reduction in density. It is noted that the blue rock sample from the built revetment structure and the rock from Mt Amos quarry has density values in excess of GHD's original 2.6 t/m^3 design criteria and assessed as 'excellent' in accordance with CIRIA.

7.2.2 Water absorption

The water absorption values of the T1 to T5 rock samples is assessed as 'marginal to poor' with values ranging from 3.1% to 10.5%. It is noted that the blue rock sample from the built revetment structure and the rock from Mt Amos quarry has water absorption values assessed as 'good' and 'excellent', respectively, in accordance with CIRIA.

7.2.3 Los Angeles abrasion

The Los Angeles abrasion values of the T1 to T5 rock samples is assessed as 'marginal to poor' with values ranging from 26% to 49%. It is noted that the blue rock sample from the built revetment structure and the rock from Mt Amos quarry has water absorption values assessed as 'excellent' in accordance with CIRIA.

7.2.4 Sodium sulphate soundness test

The sodium sulphate soundness values for all three sources are assessed as 'excellent' in accordance with CIRIA.

7.2.5 Crushing resistance

The ultimate compressive strength (UCS) values of T1 to T5 rock samples is assessed as 'poor to excellent' with the blue rock returning values assessed as 'good to excellent' in accordance with CIRIA. The point load index values of T1 to T5 rock samples is assessed as 'poor to excellent' with the blue rock returning values assessed as 'excellent'.

7.3 Development approval SPD-0414-006809 conditions

The following summary is provided on the alleged breaches to conditions 1, 2, and 4 as outlined in EHP's letter dated 2 December 2015 and condition 13 as per EHP's show cause notice dated 12 February 2016.

7.3.1 Condition 1 additional response

The site inspection carried out on the 18 February 2016, confirms the following:

- There are areas of the revetment where the slope has been constructed steeper than 1 vertical to 2 horizontal, particularly at the marina interfaces.
- The revetment structure has not been constructed in accordance with the typical sections in the amended approval drawings CSC-C001 to CSC-C003.

7.3.2 Condition 2 additional response

No further commentary, to that already provided in GHD's memorandum titled 'Webber Esplanade revetment wall' dated 5 February 2016, is required.

7.3.3 Condition 4 additional response

Based on the ‘peel back’ findings and rock testing results documented above, it is confirmed that the revetment structure does not comply with EHP’s operational policy, building and engineering standards for tidal works.

7.3.4 Condition 13 additional response

The show cause notice alleges a breach to condition 13. Condition 13 states, ‘*prevent the release of sediment to waters or a build-up of sediment in any stormwater drain.*’

It is confirmed, based on the ‘peel back’ findings above, that the placed core material is of a grading such that the release of sediment into adjacent waters is likely. As stated in 7.1, further sampling and testing of both the core and rock armour would be required in order to confirm particle size distribution and rock grading curves to further assess and define the risk of high fines content release.

8. Additional EHP requirements

8.1 Geotechnical considerations

As documented in EHP's attached minutes (refer to Appendix B), reflective of the 17 February 2016 meeting, EHP has requested '*some assurance that the foundation material is suitable and there is an acceptable level of risk*'.

In the absence of a full understanding of the actual materials that support the revetment, it is not possible to provide a total assurance of geotechnical global stability of the revetment as a whole. As GHD was not present during construction, there is very limited information available. While the recent 'peel backs' provided information on the revetment armour rock and core, no further information on foundation conditions beneath the full revetment width and depth to residual soil/weathered rock, relevant to geotechnical stability, could be obtained.

In this case, the situation is unchanged from the advices provided in GHD's letter report of 24 February 2014 where the incremental effect of the reclamation material deposition was assessed for the highest cross section as-built only, including allowing for some strength gain since time of construction, should soft clays have remained beneath the revetment. This related to static stability, whereas instability under earthquake remained an unknown, but this may or may not be as critical an event subject to EHP's and Council's requirements.

On the understanding there has been no sign of revetment distress (cracking, slumping, unusual deformation) that could be attributed to global instability, it is most unlikely that a short term undrained static failure would now occur since the revetment has existed for some time and such failures typically occur soon after construction before any significant strength gain of soft foundation soils.

However, at the time of preparation of GHD's 24 February 2014 letter report it was understood "that core material of '100-300 mm clean rock' was placed … within the entire length of the structure". This is relevant to the global stability and performance of the revetment as significant differential water pressures and hence piping of remnant foundation materials such as loose sands and soft clays (potentially not removed during construction) would be of minimal risk with a free draining core. As significant fines have now been found in the exposed core material, there is a risk of differential water levels developing as the reclaim material fills increases. With this comes the risk of larger destabilising differential water levels than assessed for the comparative global stability assessment together with the risk of foundation piping driven by the increased head if the materials and conditions are so predisposed. Again, in the absence of actual ground conditions the increased risk is unable to be readily quantified.

Turning to the actual performance, it is understood that the reclamation was completed over 18 months ago and there have been no reported occurrences of significant loss or gross deformation of the revetment crest or profile due to foundation piping or global static instability since that time including surviving a cyclonic event. It is also understood that no further loadings of a material nature will be placed affecting the revetment. On this basis, the risk of catastrophic failure reduces, noting however that piping can occur at any time and in dam structures have been recorded many years after completion. As piping events can initiate in a very localised area, attempting to determine their precise location is usually defeated even with the most intensive geotechnical investigation. For the revetment itself, a piping event would likely result in deformation rather than collapse and reshaping should be possible. The above comments do not address material release and environmental consequences.

8.2 Overtopping considerations

EHP has also requested consideration to '*whether the height of the seawall would meet the requirements of the prescribed tidal works code.*' As stated in the meeting with EHP, further investigation was undertaken by GHD for Cook Shire Council, subsequent to release and review by Council of our memorandum dated February 2014 (see Appendix F). GHD completed calculations in accordance with the Schutrumpf methodology which showed predicted overtopping jet velocity with distance from the back face of the rock amour crest, as summarised below in Table 9.

Table 9 Overtopping jet velocity with distance from crest

Overtopping jet velocity with distance from the crest						
Metres from the back face of the rock armour crest (m)	0	1	2	3	4	5
Overtopping jet velocity (m/s)	8.3	6.1	4.3	2.8	1.8	1.03

Advice to Council at the time of correspondence (dated 28 April 2014) stated that a 4 metre 'sealed' width, commencing at the back of the revetment crest, was recommended. This recommendation was provided on the basis that the immediate area adjacent to the concrete 'sealed' footpath was to be landscaped with 'trees, shrubs and irrigated couch grass' in accordance with CIRIA (C683,2007) and Brisbane City Council's Stormwater Outlets in Parks and Waterways (2003, version 2) guidance on critical scour velocities.

It is noted that landscape design and/or works have not occurred to date immediately adjacent to the concrete footpath. There is a risk of scour of the in situ sandy material adjacent to the footpath in extreme events. In addition, due to the defects in the rock revetment structure as highlighted above, it is expected that the overtopping volume and jet velocities will increase in time leading to unacceptable performance and safety risk. Based on the current state of revetment construction and crest treatment, it is concluded that the current crest treatment does not comply with the design event criteria under EHP's operational policy, building and engineering standards for tidal works.

9. References

Brisbane City Council, *Stormwater Outlets in Parks and Waterways, Appendix A Outlet Erosion Control*, Witheridge 2003.

CIRIA, *C683 The Rock Manual*, (2007) (referred as Rock Manual)

CIRIA, Special Publication 83, Report 154, *Manual on the use of rock in coastal and shoreline engineering*, (1991).

GHD, *'Webber Esplanade revetment wall'* Memorandum, dated 5 February 2016.

GHD, *'As-Constructed' Rock Revetment'* Memorandum, dated 24 February 2014.

Appendices

Appendix A – Memo report in response to EHP letter dated 2 December 2015

Appendix B – EHP minutes of meeting 17 February 2016

Appendix C – Cardno rock testing results

Appendix D – Mt Amos quarry rock testing results

Appendix E – Updated survey analysis

Appendix F – GHD ‘As-constructed’ rock revetment Memorandum February 2014

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